#507208 (5)

Coatings with Selected Infrared Properties For Use On CF Ships

by

Dr. Terry Foster
Head, Dockyard Laboratory Esquimalt, Esquimalt Defence Research Detachment
P.O. Box 17000 STN FORCES
Victoria BC V9A 7N2

and

David Hacker and Bill Abel
ORTECH Corporation
2395 Speakman Drive, Mississauga, ON L5K 1B3

ABSTRACT

Infrared properties of coatings used on naval vessels are important in maintaining ship habitability, i.e. reducing heat build-up in compartments and protecting equipment from excessive temperatures. Coatings can also be used to control the infrared signature of a ship.

In this presentation, a brief overview of the various properties of infrared radiation (solar, near and thermal infrared) and the significance of infrared radiation for naval vessels will be given. Various ways of changing the solar infrared, near infrared and thermal infrared properties of coatings such as choice of pigment content, resin type and surface property will be presented along with the effects these changes can have on the temperature and IR reflectivity of the coated surface.

Finally, the development of new solar reflective coatings for naval vessels will be presented. These new coatings reflect up to 80% of the incident solar infrared radiation, as compared to 30% for the currently used coatings. These coatings will significantly affect the surface temperature of the ship sides and decks and contribute to a reduction in the IR signature of the ship.

COATINGS WITH SELECTED INFRARED PROPERTIES

Dr. Terry Foster,

Head Dockyard Laboratory Esquimalt, EDRD

Mr. David Hacker

Manager Coatings and Adhesives

ORTECH

Coating Properties of Interest

- Visual Camouflage
- Ice Release Properties
- Non-Skid Properties
- Ease of Application
- Maintainability
- Cosmetic Appearance
- Corrosion Resistance
- Durability
- Cleanability
- Toxicity or Hazardous Components

25410-01452/102-201

Cosmetic

- CHOICE OF COLOUR
- CHOICE OF GLOSS OR REFLECTIVITY
- EASE OF CLEANING AND MAINTENANCE
- CORROSION PROTECTION USUALLY THE FUNCTION OF THE PRIMER
  - INORGANIC ZINC OR ZINC RICH EPOXY

Coating to Control Radiation

- Reduce excessive heating of equipment due to absorption of solar radiation
- Reduce signature (IR, NIR and VIS) by decreasing emission of radiation in the IR and visual regions
- Absorb solar radiation for solar heating systems
- Transmit visible light while filtering out IR wavelengths (architectural glass)

Coating Requirements to Control Emission

- Coatings Which Act by Controlling Reflectance of Incident Solar Radiation, Predominantly Visible and NIR
- Coatings Can Control Emissions Resulting From a Combination of Reflected Incident Solar Radiation and Thermal Self Emitted Radiation Which Is a Function of the Emisivity and Temperature of the Radiating Surface. These Coating Operate in the Visible, NIR, Mid -IR and Far - IR

Signature and Vis/IR Frequencies

- Visible
  - 400 - 720 nm (0.4 - 0.72 um)
- Near Infrared (NIR)
  - 700 - 2300 nm (0.7 - 2.3 um)
- Thermal Infrared (TIR)
  - 2.5 - 15 um
  - 3-5 um and 8-14 um are the bands of interest for thermal missile and surveillance
- Distribution of Solar Energy
  - 5% ultra-violet (less than 400 nm)
  - 45% in the visible region
  - 50% in the solar infrared region.

Visible and IR Radiation of Coatings

- The solar radiation striking a coated surface is either reflected, absorbed or transmitted at each interface
  - coating surface / air
  - internal coating - pigment and resin
  - substrate
- The reflected radiation can be either specular (mirror-like) or diffuse (scattered) and is dependent on the pigments used in the coating or the texture of the surface.
- Radiation not reflected from the film is converted into heat or chemical energy

Infrared Radiation

- Objects having temperatures of 300°K are strong sources of thermal infrared radiation and emit 98% of their total radiation in the 3-30 um region
- Overlap between reflected solar and emitted is in the 3-5 um region
- Therefore "at room temperature, the power emitted at 5 um by an efficient radiator is as great as the power from sunlight falling on the same area" (black body energy in 3 - 5 um = 4×10^{-2} W/m^2)
- In the 8-13 um region reflected solar radiation is not very important (black body energy in 8 -13 um = 1×10^{-4} W/m^2)

Infrared Radiation

- Objects having temperatures of 300°K are strong sources of thermal infrared radiation and emit 98% of their total radiation in the 3-30 um region
- Overlap between reflected solar and emitted is in the 3-5 um region
- Therefore "at room temperature, the power emitted at 5 um by an efficient radiator is as great as the power from sunlight falling on the same area" (black body energy in 3 - 5 um = 4×10^{-2} W/m^2)
- In the 8-13 um region reflected solar radiation is not very important (black body energy in 8 -13 um = 1×10^{-4} W/m^2)

Reflection and Absorption

- The radiation reflected has not been absorbed and thus has not affected the thermal properties of the coating and substrate.
- It is the absorbed radiation that affects the thermal energy of the substrate and the transmitted radiation that contributes to the thermal or IR signature.
- For optimum camouflage the reflective properties of a coating in the visible and infrared regions must be similar to its surrounding in either natural or artificial light such that the coated object is indistinguishable from its surroundings.

Reflectivity / Emissivity

Reflectivity/Emissivity of Materials

	Emissivity	Reflectivity
Blackbody	1	0
Glass	0.94	.04
Rubber	0.8	0.2
Steel	0.6	0.4
Stainless Steel	0.09	0.91
Aluminum	0.08	0.92
Silvered Mirror	0.02	0.98
Ocean (SS4)	~0.8	~0.2

Resins and IR Coatings

- Resins must transparent in the IR region of interest as well has have the properties required to make a good paint film
- Resins generally do not absorb in the NIR region and most can be used in this region
- In the thermal IR region organic resins have absorption bands at 3.3 um (C-H stretch), 5.7 um (C-H bending) and 8.0 um (C=O stretch)
- Absorption by resins can also be reduced by the selection of pigments that scatter light in the region of concern

Pigments and IR Coatings

- Pigments form the major contribution to the IR properties of coatings
- The combination of diffuse and specular reflectance, absorption and transperance properties of a pigment in the IR define its IR properties
- Particle size will also affect diffuse reflectance properties due to light scattering
- Brady (US) and Wake (AS) have measured the IR properties of pigments in a standard paint film over the spectral range 400nm to 2300 nm using diffuse reflectance techniques
- Pigments were then classified into six categories

Pigment Classification

- Transparent
  - Amorphous Silica
- Reflective
  - Titanium Dioxide (10 um)
- Highly Reflective
  - Titanium Dioxide (2 um)
- Absorbent-Transparent
  - Palogen Black
- Reflective-Transparent
  - Chromium Oxide
- Highly Absorbent
  - Black Iron Oxide

Scattering Power

- Scattering of radiation is a function of the difference between the refractive index of the pigment and the resin
- Refractive index of commercial pigments varies between 1.4 and 2.8
- The scattering power (*m*) the ratio of the refractive index of the pigment to the resin
- Hiding pigments have m above 1 (TiO_2, red iron oxide *m*=1.9) - hide the substrate by modifying the reflectance curve of the substrate
- Extender pigments have values of *m* at or below 1.1 - talc (1.07) or silica (0.97- 1.05)

Particle Size

- From scattering power measurements, refractive index and particle size the wavelength for most efficient scattering can be determined
  - e.g. TiO_2 particle size 200 nm wavelength of 500nm
  - TiO_2 and Red Iron Oxide 1 um particle sizes would be required to scatter NIR at 2.3 um
  - For NIR particles sizes of the order of mm would be required

Objectives

- Evaluate the current infrared properties of the topside alkyd and non-skid deck coatings
- Reformulate these coatings to enhance the reflectivity in the 700-1000 nm region and maintain the colour requirements for visual camouflage
- Evaluate by thermography the thermal properties of the reformulated coatings

Coating Preparation - 1

- Pigment pastes were made from a variety of combinations of pigments as suggested by the pigment manufacturers
- Pigment pastes where then dispersed in an alkyd resin and ground to a Hegman fineness of 6.5-8 using a ball mill
- Tints for the urethane coatings were dispersed in an acrylic resin
- These tints and pastes were then used to formulate urethane and alkyd coatings

Coating Preparation - 2

- Colour matching was carried out using a daylight source as many of the formulations were metameric
- Metameric - appears to be the same colour but colour will differ under different lighting conditions
- Final formulations were tested for resistance to salt spray, accelerated weathering and adhesion to substrate and primer
- Thermography was carried to determine the heat reflective effect of each coating

Pigments and Suppliers

Manufacturer	Pigment	Type	Price ($/kg)
BASF	Paliogen Black L0084	Perylene	$210.00
	Paliogen Black L0086	Perylene	$210.00
Bayer	Red Oxide 130M	Iron oxide	$3.31
	Yellow Oxide 3910	Iron oxide	$3.42
Ciba-Geigy	IRGACOLOR Black 10333	Chrome iron nickel black spinel	$20.00
	IRGACOLOR Buff 10406	Chrome antimony titanium rutile	$11.00
	IRGACOLOR Green 10405	Cobalt chromite green spinel	$26.30
	IRGACOLOR Green 10342	Cobalt titanate green spinel	$41.15
	IRGALITE Green GLN	Polychloro copper phthalocyanine	$30.50
	IRGAZIN Yellow 3RLTN	Isoindolinone	$93.10
Harshaw	9885 Meteor Plus High IR Black	Iron chromite brown spinel	$25.75

Pigments and Suppliers

Manufacturer	Pigment	Type	Price ($/kg)
Ferro Corp.	V-700 Black	Chromium green/black hematite	$18.06
	V-9238 Blue	Cobalt chromite blue/green spinel	$59.77
	V-11674 Green	Chromium (III) oxide	$9.59
	V-11692 Green	Chromium (III) oxide	$9.59
	V-12600 Green	Cobalt chromite green spinel	$25.05
	G 6099 Green	Chromium (III) oxide	$12.00
Harcros Pigments, Inc. (Engelhard Corp.)			
Shepherd Color Co.	Green 179	Cobalt chromite green spinel	$17.84
	Green 4	Cobalt titanate green spinel	$18.24
	Black 123	Chrome, iron oxides	$14.52
	Black 376	Chrome iron nickel black spinel	$18.15
	Yellow 195	Nickel antimony titanium yellow	$9.83
	Gray A8151	Mixed metal oxides	$0.75

Aklyd 501-109

- Six formulations of grey alkyd were prepared and the VIS/NIR reflectance were compared to a standard grey alkyd (General Paints)
- Reflectance at 900 nm varied from 42% for the standard to 51% to 81% for the new formulations
- Costs for formulation 7222-57 using perylene black are much higher than for 7222-68 using mixed metal oxides

GP-61, 501-109 Matches

Clear Base	Amt.
Aroplaz 2502-ML-60	84.243
Xylene	15.164
NeoCem 250	0.147
Dri Rx	0.147
Nuxtra cobalt 12%	0.152
Exkin #2	0.147
	100

White Base	Amt.
Aroplaz 2502-ML-60	58.353
Kronos 2102	35.012
Xylene	6.224
NeoCem 250	0.102
Dri Rx	0.102
Nuxtra cobalt 12%	0.105
Exkin #2	0.102
	100

7222-55	Amt.
Clear Base	27.79
White Base	63.31
Ferro V12600	3.59
Ferro V11674	2.78
Ferro V700	2.53
	100

7222-57	Amt.
Clear Base	26.24
White Base	69.36
Ferro V12600	2.08
Ferro V11674	0.92
BASF L0086	1.39
	100

GP-61, 501-109 Matches

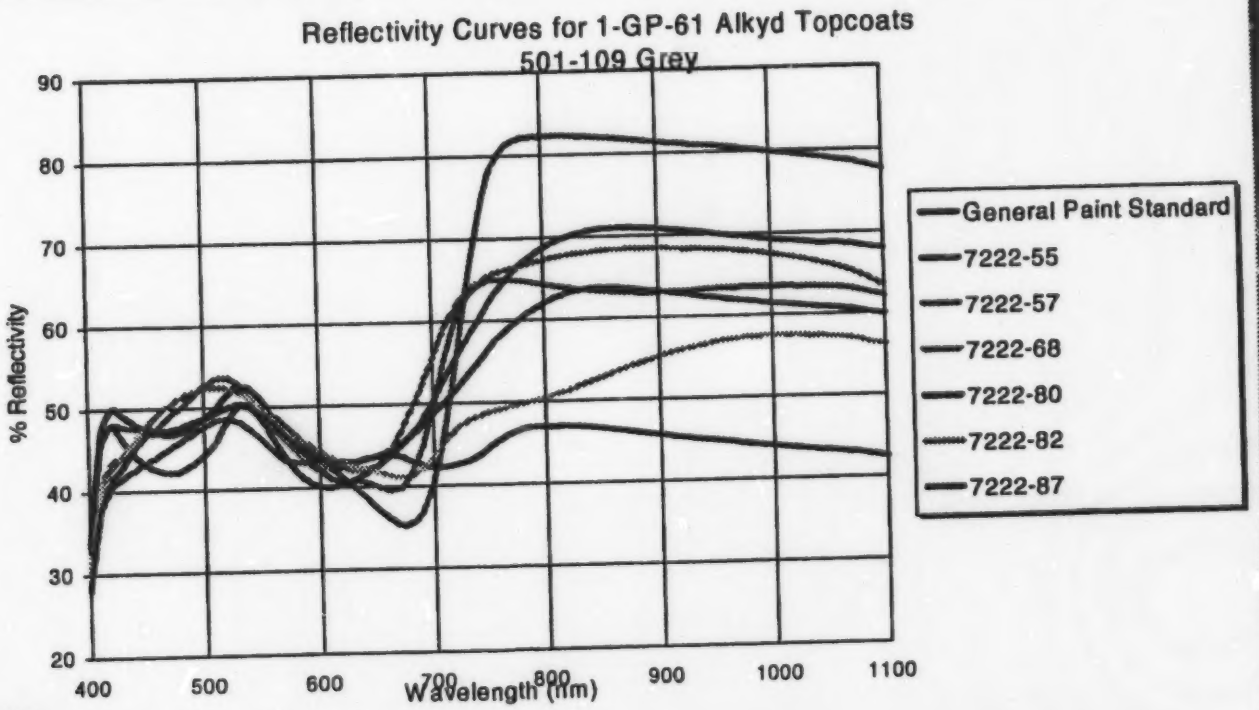
7222-62	Amt.
Clear Base	26.96
White Base	55.76
Shepherd A8151	9.46
Shepherd 195	1.35
Shepherd 179	6.47
	100

7222-82	Amt.
Clear Base	28.66
White Base	58.72
Shepherd 4	4.36
Shepherd 179	3.62
Shepherd 376	2.01
Shepherd 195	2.62
	100

7222-80	Amt.
Clear Base	24.51
White Base	64.73
Shepherd 179	3.27
Ferro V11674	5.25
Harshaw 9885	2.25
	100

7222-87	Amt.
Clear Base	26.53
White Base	70.76
Ciba 10405	2.39
Ciba 10406	0.21
Bayer 130M	0.12
	100

Alkyd Topcoats



Non-Skid - Dark Green, 503-305

- Four formulations of dark green non-skid were prepared and the VIS/NIR reflectance were compared to a standard green non-skid (Tibbetts)
- Reflectance at 900 nm varied from 6% for the standard to 20% to 50% for the new formulations
- The perylene black formulation gave the best performance but the matches using the Shepard and Ferro pigments matches gave similar performance at less cost

1-GP-200, 503-305 Matches

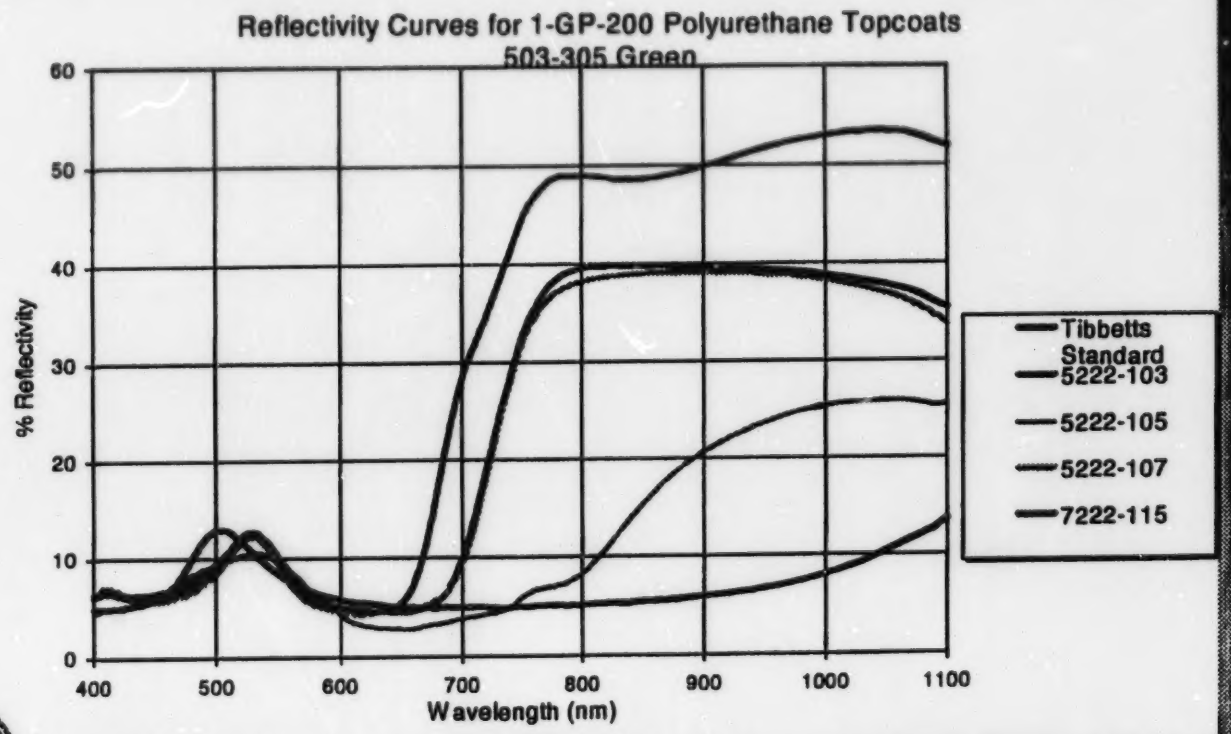
7222-125	
Clear Base	29.30
White Base	0.35
Ferro V12600	2.77
Ferro V11692	5.13
Ferro V9238	1.70
Ferro V700	0.87
Talc	43.93
PE Fibre	2.87
Desmodur E 3265	13.09
	100.00
Glass	58.30
	158.30

7222-127	Amt.
Clear Base	28.93
White Base	2.71
Ciba 3RLTN	0.61
Ciba 10342	3.58
Ciba 10333	1.75
Ciba GLN	1.81
Bayer 3910	0.10
Talc	43.91
PE Fibre	2.84
Desmodur E 3265	13.76
	100.00
Glass	58.30
	158.30

7222-122	Amt.
Clear Base	21.11
White Base	1.75
BASF L0084	4.19
Harcros 6069	8.26
Ferro V9238	3.00
Huls C844-2862	1.18
Talc	44.82
PE Fibre	2.83
Desmodur E 3265	13.00
	100.00
Glass	58.30
	158.30

7222-124	Amt.
Clear Base	27.81
White Base	0.92
Shepherd 179	8.25
Harcros 6090	2.66
Talc	44.55
PE Fibre	2.82
Desmodur E 3265	13.00
	100.00
Glass	58.30
	158.30

Green Polyurethane



Non-Skid - Dark Grey, 501-302

- Two formulations of grey non-skid were prepared and the VIS/NIR reflectance were compared to a standard grey non-skid (Tibbetts)
- Reflectance at 900 nm varied from 8% for the standard to 39% to 44% for the new formulations
- The formulation using perylene black gave the most improved reflectance but at a significantly higher pigment cost

GP-200, Base Formulation and 501-302 Matches

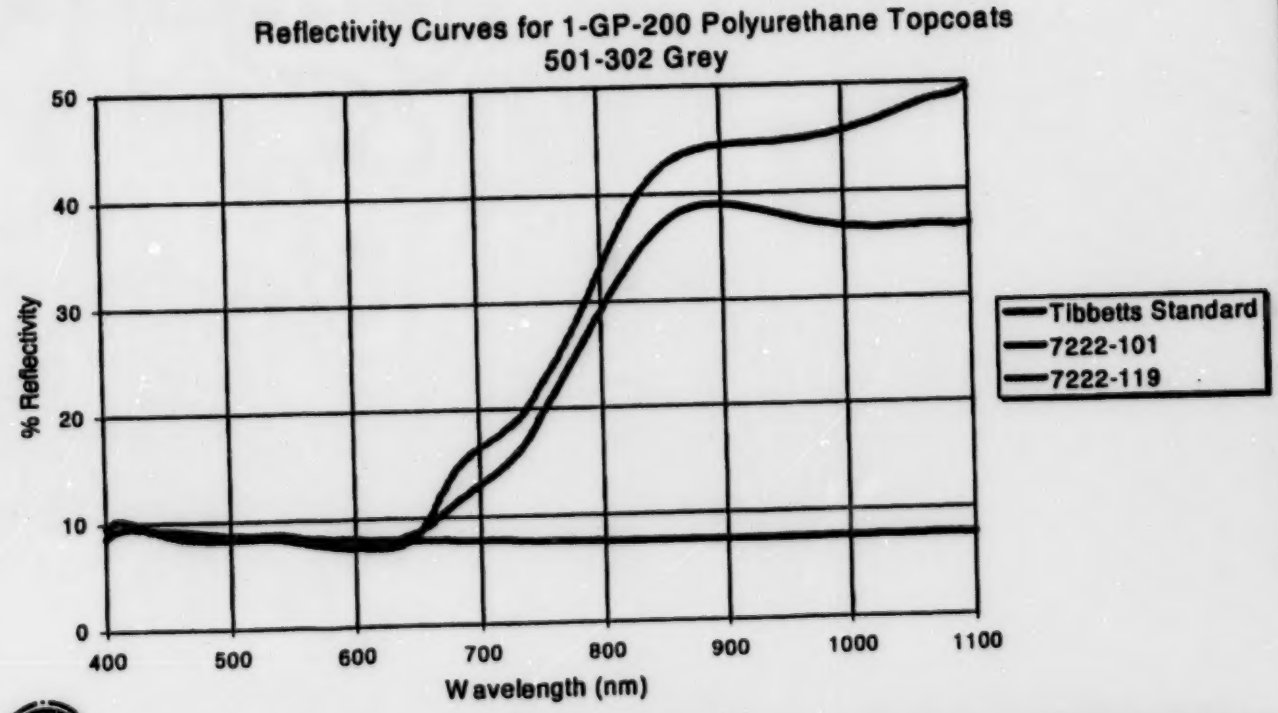
Clear Base	Amt.
Desmophen A 160	85.967
Xylene	14.033
	100.00

White Base	Amt.
Desmophen A 160	63.158
Kronos 2102	26.316
Xylene	10.526
	100.00

7222-126	Amt.
Clear Base	38.46
White Base	4.35
Ferro V700	8.64
Ferro V9238	1.56
Talc	19.60
PE Fibre	1.40
Desmodur E 3265	13.17
Xylene	12.82
	100.00
Glass	58.30
	158.30

7222-82	Amt.
Clear Base	46.26
White Base	4.89
BASF L0084	1.90
Shepherd 123	20.01
Talc	8.00
PE Fibre	1.45
Desmodur E 3265	17.48
	100.00
Glass	58.30
	158.30

Grey Polyurethane



Test Methods

- Resistance to salt spray ASTM B 117-94 for 240 hours
  - Panels were not scribed and corrosion and blistering were monitored
- Accelerated weathering was carried out for 360 hours in a xenon arc weatherometer
  - Observations were made for colour and gloss changes on the alkyd system and colour changes on the polyurethane system
- Adhesion to substrate was carried out according to ASTM D 3359-93 (Cross-Cut Method)

Accelerated Weathering GP-61

Reference	Initial Colour	Final Colour	Difference	Initial Gloss (60°)	Final Gloss (60°)	Difference
General Marine 1-GP-61 501-109	L* 74.28 a* -6.11 b* 1.66	L* 74.79 a* -5.93 b* 0.64	ΔE 1.16 ΔC -0.37 ΔH 0.97	79.6	55.3	-24.3
7222-55	L* 73.03 a* -5.43 b* 0.21	L* 74.19 a* -5.52 b* -0.78	ΔE 1.52 ΔC 0.13 ΔH 0.98	81.5	68.3	-13.2
7222-57	L* 73.16 a* -6.22 b* 0.62	L* 73.32 a* -5.74 b* -0.72	ΔE 1.43 ΔC -0.46 ΔH 1.35	83.7	72.3	-11.4
7222-68	L* 73.32 a* -8.55 b* 2.40	L* 73.86 a* -8.38 b* 1.02	ΔE 1.49 ΔC -0.44 ΔH 1.32	82.5	43.5	-39.0
7222-87	L* 73.33 a* -6.84 b* 2.88	L* 74.23 a* -6.61 b* 2.45	ΔE 1.02 ΔC -0.37 ΔH 0.31	87.6	82.8	-4.8

Accelerated Weathering GP-200

Reference	Initial Colour	Final Colour	Difference
Tibbetts 1-GP-200 501-302	L* 29.39 a* -0.22 b* -2.29	L* 28.33 a* -0.35 b* -2.02	ΔE 1.09 ΔC -0.24 ΔH -0.16
7222-123	L* 32.86 a* 1.22 b* -0.08	L* 33.20 a* 1.37 b* -0.04	ΔE 0.37 ΔC 0.14 ΔH 0.05
7222-126	L* 35.29 a* -0.28 b* -2.26	L* 35.66 a* -0.19 b* -2.13	ΔE 0.40 ΔC -0.13 ΔH 0.07

Accelerated Weathering GP-200

Reference	Initial Colour	Final Colour	Difference
Tibbetts 1-GP-200 503-305	L* 28.79 a* -15.13 b* 3.92	L* 27.35 a* -13.84 b* 4.38	ΔE 1.99 ΔC -1.11 ΔH -0.80
7222-122	L* 33.21 a* -8.32 b* 3.81	L* 34.47 a* -8.69 b* 4.13	ΔE 1.35 ΔC 0.47 ΔH -0.13
7222-124	L* 36.46 a* -15.39 b* 5.11	L* 37.37 a* -15.45 b* 5.32	ΔE 0.94 ΔC 0.12 ΔH -0.18
7222-125	L* 32.72 a* -9.47 b* 2.89	L* 33.31 a* -9.43 b* 2.91	ΔE 0.60 ΔC -0.04 ΔH -0.02
7222-127	L* 34.43 a* -15.29 b* 2.67	L* 34.58 a* -15.17 b* 2.80	ΔE 0.23 ΔC -0.10 ΔH -0.15

Adhesion to Primer

Reference	Before Weathering	After Weathering
General Marine 1-GP-61 501-109	4A	4A
7222-55	3A	3A
7222-57	2A	2A
7222-68	2A	3A
7222-80	3A	N/A
7222-82	3A	N/A
7222-87	4A	4A
Tibbetts 1-GP-200 501-302	5A	5A
7222-123	5A	5A
7222-126	5A	5A
Tibbette 1-GP-200 503-305	5A	5A
7222-122	5A	5A
7222-124	5A	5A
7222-125	5A	5A
7222-127	5A	5A

Results of Exposure

- None of the formulations showed any signs of corrosion or blistering
- None of the formulations showed any significant colour changes
- The gloss changes for GP-61 were less than that for the control
- Alkyd systems gave weak to acceptable adhesion results
- All urethane systems gave excellent adhesion results

Thermography

- Solar energy produced by Vortek^{tm} 150 kW Solar Simulator Lamp (Mll No. A06264)
- Distance panels to lamp 29 ft
- Light intensity at panels 970-980 W/m^2
- Panels mounted side by side 30^o from vertical, incident light normal to surface
- Temperatures monitored with thermocouple soldered to back of panels
- Thermography carried out after panels reached equilibrium - 15 minutes for GP-61 and 20-30 minutes GP-200

Thermography

- Agema 470 Thermovision infrared camera - accuracy is either 2°C or 2%, which ever is less
- Warmer surfaces indicated by lighter colours (orange-red-white)
- Cooler surfaces indicated by darker colours (violet-blue-black)
- In each case the standard panels exhibited higher emissivity, formulated coatings were more reflective
- Emissivity values are relative and cannot be compared between sets

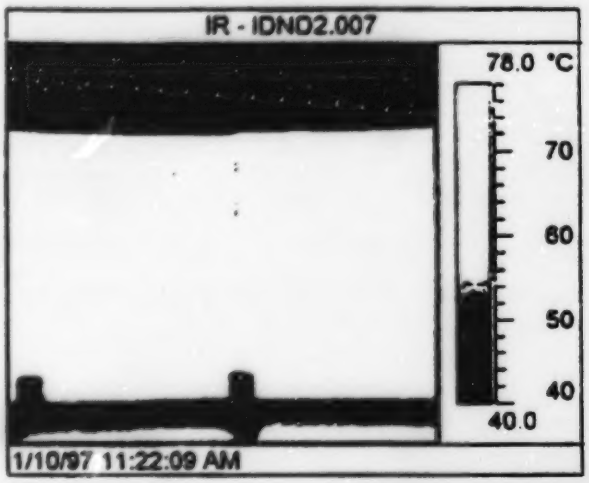
Thermography Results

Coating	Standard	Experimental	Difference
1-GP-61, 501-109 7222-57	52.8°C	44.0°C	8.8°C
1-GP-200, 501-302 7222-123	70.1°C	62.6°C	7.5°C
1-GP-200, 503-305 7222-122	69.3°C	60.9°C	8.4°C

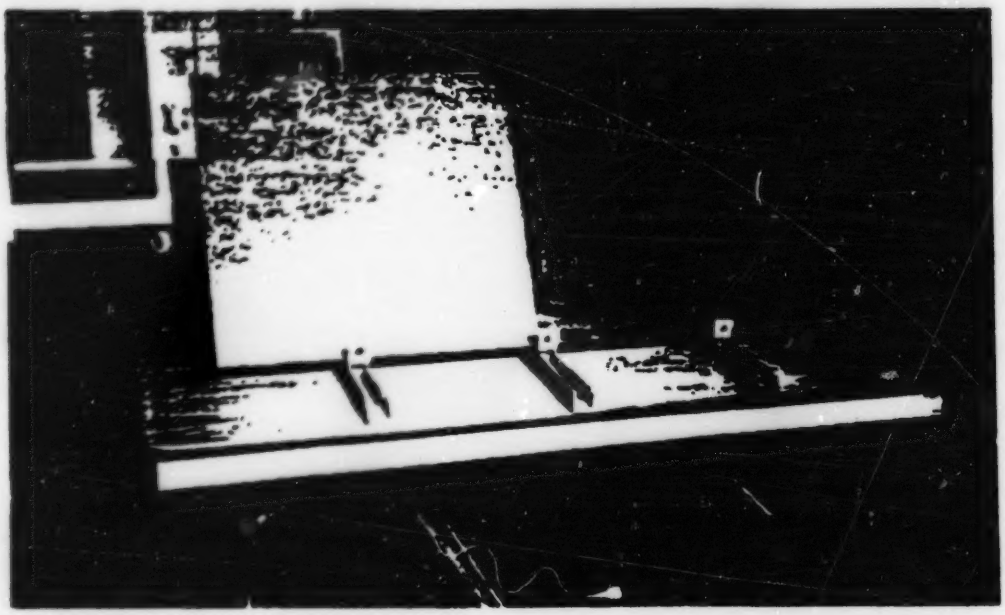
Conclusions

- Six variants of grey alkyd, 501-109 have been formulated with good solar reflective properties
- Further work required to confirm IR reflectance properties in the 3-5 um region
- Two variants of grey and four variants of green polyurethane non-skid have been formulated with increased solar reflectance properties
- Currently investigating the development of a commercial formulation of the non-skid for future ship trial

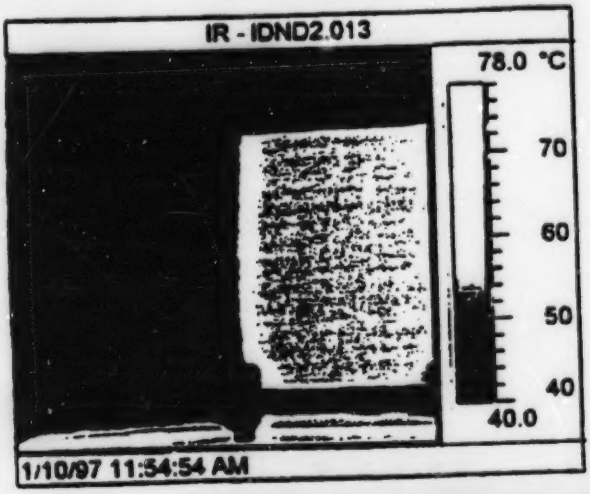
1-GP-200, 501-302 Dark Grey Panels	
7222-123	Tibbets Standard
Reverse side panel temperature = 62.6°C	Reverse side panel temperature = 70.1°C
Assumed face panel temperature = 67.6°C	Assumed face panel temperature = 75.1°C
Calculated emissivity = 0.87	Calculated emissivity = 0.92



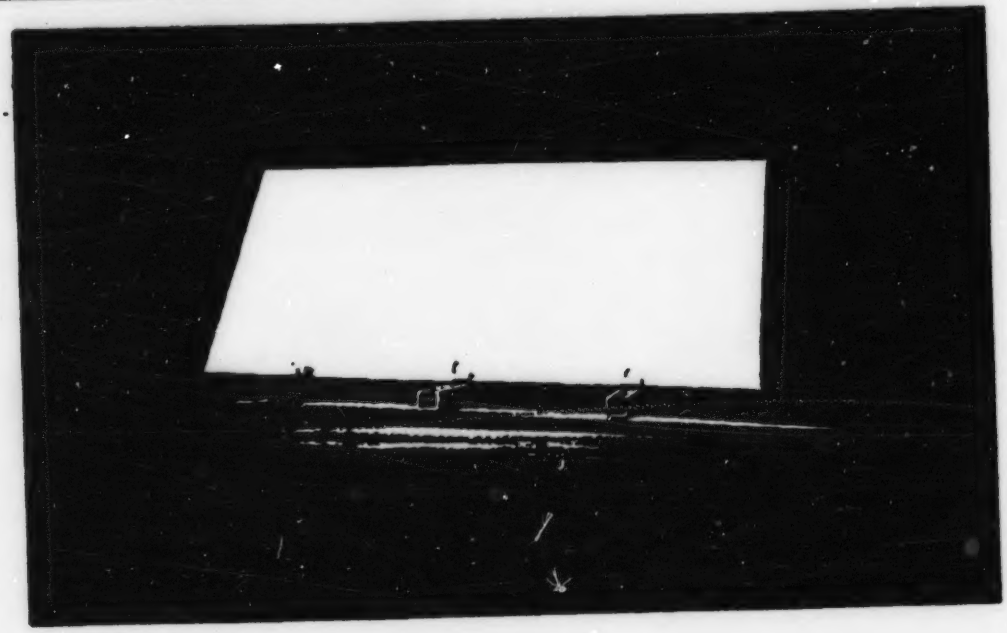
SCANNER DATA	
Level	471
Sens	6
Aperture	0
Filter	NOF
Lens	20
IMAGE OBJ. PAR.	
Emissivity	0.90
Amb. temp.	30.2 °C
Atm. temp.	27.0 °C
Object dist.	3.0 m
Transmission	0.97



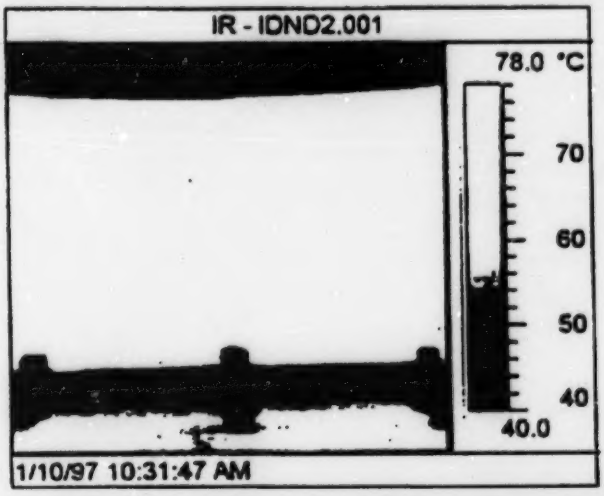
1-GP-61, 501-109 Light Grey Panels	
7222-57	General Paint Standard
Reverse side panel temperature = 44.0°C	Reverse side panel temperature = 52.8°C
Assumed face panel temperature = 49.0°C	Assumed face panel temperature = 57.8°C
Calculated emissivity = 0.95	Calculated emissivity = 1 00



SCANNER DATA	
Level	913
Sens	7
Aperture	0
Filter	NOF
Lens	20
IMAGE OBJ. PAR	
Emissivity	0.97
Amb. temp	30 5 °C
Atm. temp	28 6 °C
Object dist.	3.0 m
Transmission	0.97



1-GP-200, 503-305 Dark Green Panels	
7222-122	Tibbets Standard
Reverse side panel temperature = 60.9°C	Reverse side panel temperature = 69.3°C
Assumed face panel temperature = 65.9°C	Assumed face panel temperature = 74.3°C
Calculated emissivity = 0.89	Calculated emissivity = 0.92



SCANNER DATA	
Level	471
Sens	6
Aperture	0
Filter	NOF
Lens	20
IMAGE OBJ. PAR	
Emissivity	0.91
Amb. temp.	29.2 °C
Atm. temp.	25.7 °C
Object dist.	3.0 m
Transmission	0.97